MODELING ROBOT SWARMS USING AGENT-BASED SIMULATION

Alistair Dickie,-Captain, Australian Army
BSc(Hons), University College (University of New South Wales), 1995
Master of Science in Operations Research-June 2002
Thesis Advisor: Gordon Bradley, Department of Operations Research
Thesis Advisor: John Hiles, MOVES Institute
Second Reader: Arnold Buss, Department of Operations Research

ABSTRACT

In the near future advances in mechanical and electrical engineering will enable the production of a wide variety of relatively low cost robotic vehicles. This thesis investigates the behavior of swarms of military robots acting autonomously. The Multi-Agent Robot Swarm Simulation (MARSS) was developed for modeling the behavior of swarms of military robots. MARSS contains state, sensing, and behavioral model building tools that allow a range of complex entities and interactions to be represented. It is a model-building tool that draws theory and ideas from agent-based simulation, discrete event simulation, traditional operations research, search theory, swarm theory, and experimental design. MARSS enables analysts to explore the effect of individual behavioral factors on swarm performance. The performance response surface can be explored using designed experiments. A model was developed in MARSS to investigate the effects of increasing behavioral complexity for a search scenario involving a swarm of Micro Air Vehicles (MAV's) searching for mobile tanks in a region. Agreement between theoretical and simulated search scenarios for simple searchers was found. The effect of increased MAV sensory and behavioral capability was demonstrated to be important. Little improvement was observed in swarm performance with these capabilities, however agent performance was adversely affected by reacting to increased knowledge in the wrong way. The utility of MARSS for conducting this type of analysis was demonstrated.

EXECUTIVE SUMMARY

In the near future advances in mechanical and electrical engineering will enable the production of a wide variety of relatively low cost robotic vehicles. These vehicles will be physically capable of performing many military tasks in all spheres of the battlespace. Most current and planned military robotic vehicles involve a single person controlling many vehicles. When the battlespace has thousands of robots this will become impractical. Humans will instead interact with groups of robots. Individual robots within the group will act autonomously to achieve a common goal. These groups of robots are known as swarms.

Modeling can help determine important behavioral and sub-system design considerations. Analytical models do not have the ability to answer the most pressing issues, such as how an individual robot should behave and how they should interact with each other in order to produce a desired swarm goal. Simulation can help answer these questions; in particular, agent-based simulation has constructs for representing knowledge, behavior, and interactions. The representation of these aspects of a swarming robot system is vital to understand the system as a whole.

The primary aim of the work reported in this thesis was to develop, implement, and test a model for investigating the behavior of swarms of robots. A simulation tool called the Multi-Agent Robot Swarm Simulation (MARSS) was developed. MARSS is a sophisticated simulation model-building tool that can be used by analysts to understand the contribution that individual behavioral characteristics make to group performance.

The modeling methodology described in this thesis uses ideas and technologies from agent-based simulation, discreet-event simulation, stochastic models, swarming theory, search theory, design of experiments, and statistics. No proper subset of these technologies is adequate to address the modeling questions.

The modeling of a robot swarm scenario in MARSS starts with defining the problem and understanding the system that is to be studied. The sensing process in MARSS models agent interaction. The aim of the sensing model in MARSS is to transfer

information about one agent's state to another. It consists of modeling the physical process involved with transferring energy through the environment.

The behavioral process in MARSS models agents' actions. Factors control the operations of the behavioral function. The actions of many agents produce an emergent group behavior. This behavior is measured and recorded, together with the factors that produce that response. Experiments are designed to get a good spread of factor levels over the response surface. Statistics, in particular regression trees, are then used to understand what factors contributed to the response.

This modeling method was tested on a search scenario involving Micro Air Vehicles (MAV's). The results from basic MAV search scenarios implemented in MARSS were validated against analytical results for exhaustive and random search for a moving target. In both cases the results from MARSS matched those determined analytically.

More complex scenarios searchers were created where MAV's were given a more involved behavior, allowing them to react to observed targets, each other, and targets observed by fellow searchers. The searchers were conducting a random search with these modifications. Summing the components of acceleration in different directions controlled movement. It was found that by using the movement mechanism involving accelerating towards the current way point that search performance improved over the pure random search by at least 10% regardless of the configuration of the targets.

When targets were moving in a group the most important factor affecting good search performance was acceleration away from an observed target. This was an artificial result based on the configuration of the sensor. Acceleration away from other searchers, and towards targets observed by other agents was found to have only a slight affect on performance.

The research question addressed for the MAV scenario was "How should individual agents behave to produce a desired swarm behavior?" This question was answered for the MAV scenario by determining what factor levels contribute to good search performance.

Insight was provided into how the level of swarm performance is dependant on the level of communication by investigating the effects of being able to react to fellow searchers, and to targets found by fellow searchers. The results of this thesis suggest that the sharing of this information does not have a marked impact on the best swarm performance observed. A more interesting result is that reacting to that information in the wrong way can drastically reduce swarm performance.

The difference in swarm performance between Multi-Agent (distributed) and Single-Agent (centralized) swarm control was addressed by comparing the exhaustive search results to the distributed control of the complex scenarios. When targets were moving in a group, distributed control appeared to be much better; this result is somewhat artificial due to the sensor configuration. When targets were spread over the search area, distributed control did not achieve as well as central control, however the increased in performance observed does suggest that this may be possible.

Implementing and testing the MARSS model achieved the primary aim of this work. The utility of MARSS for conducting analysis of the behavior of robot swarms was demonstrated. Researchers that are considering investigating groups of robots have the MARSS tool available.

MARSS is available for download from http://diana.or.nps.navy.mil/~ajdickie/marss.